

Two-zero Majorana textures in the light of the Planck results

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Abstract

The recent results of the Planck experiment put a stringent constraint on the sum of the light neutrino masses, $\Sigma_i m_i < 0.23$ eV (95% CL). On the other hand, two-zero Majorana mass matrix textures predict strong correlations among the atmospheric angle $\sin^2 \theta_{23}$ and Σ . We use the Planck result to show that, for the normal hierarchy case, the texture with vanishing (2, 2) and (3, 3) elements is ruled out at a high confidence level; in addition, we emphasize that a future measurement of the octant of θ_{23} (or the 1σ determination of it based on recent fit to neutrino data) will put severe constraint on the possible structure of the Majorana mass matrix. The implication of the above mentioned correlations for neutrinoless double β -decay are also discussed, for both normal and inverted orderings.

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1 Introduction

The recent results from solar, atmospheric and reactor neutrino experiments have proven that neutrinos are massive, with at least two of them being non-relativistic today. Beside the values of the two squared mass differences and mixing angles [1, 2, 3]⁴, recently the Planck Collaboration [4] has released a quite stringent upper bound on the sum of the active neutrino masses:

$$\Sigma \equiv \sum_i m_{\nu_i} < 0.23 \text{ eV} \quad 95\% \text{ CL} . \quad (1)$$

This limit has been obtained assuming three species of degenerate massive neutrinos and a Λ CDM model and it stems from the combination of the Planck temperature power spectrum with a WMAP polarization low-multipole likelihood at $\ell \leq 23$ and the Baryon Acoustic Oscillation data. The above upper limit can be converted into a limit on the absolute scale of neutrino masses that reads $m_{\min} \lesssim 0.07 \text{ eV}$.

In addition, the South Pole Telescope Collaboration released a fit analysis that indicates a preferred value for the sum of the light neutrino, $\Sigma = 0.32 \pm 0.11 \text{ eV}$, with a 3σ detection of positive neutrino mass in the range $[0.01, 0.63] \text{ eV}$ at 99.7 % C.L. [5]. This result will be tested by the KATRIN experiment which is expected to have a sensitivity around 0.2 eV [6]. All this has revived some interest in connection with theories of neutrino mass generation predicting a quasi-degenerate (QD) spectrum for the light active neutrinos.

The bounds and values described above however are not definitive and other forthcoming observations will test them. The EUCLID survey [7] will be able most likely to measure the neutrino mass sum at the 0.01 eV level of precision combining the data with measurements of the CMB anisotropies from the Planck mission. Such an outstanding precision will be able to unveil the absolute scale of neutrino masses [8], being the minimum of the sum compatible with current neutrino oscillation data $\Sigma_{\min} = 5.87 \times 10^{-2} \text{ eV}$ for a normal hierarchical (NO) spectrum and $\Sigma_{\min} = 9.78 \times 10^{-2} \text{ eV}$ for an inverted hierarchical spectrum (IO).

	best fit $\pm 1\sigma$	3σ range
$\sin^2 \theta_{12}$	$0.306^{+0.012}_{-0.012}$	$0.271 \rightarrow 0.346$
$\sin^2 \theta_{23}$	$0.446^{+0.007}_{-0.007} \oplus 0.587^{+0.032}_{-0.037}$	$0.366 \rightarrow 0.663$
$\sin^2 \theta_{13}$	$0.0229^{+0.0020}_{-0.0019}$	$0.0170 \rightarrow 0.0288$
$\Delta m_{12}^2 [10^{-5} \text{ eV}^2]$	$7.45^{+0.19}_{-0.16}$	$6.98 \rightarrow 8.05$
$\Delta m_{31}^2 [10^{-3} \text{ eV}^2] \text{ (NO)}$	$+2.417^{+0.013}_{-0.013}$	$+2.247 \rightarrow +2.623$
$\Delta m_{32}^2 [10^{-3} \text{ eV}^2] \text{ (IO)}$	$-2.410^{+0.062}_{-0.062}$	$-2.602 \rightarrow -2.226$

Table 1: *Three-flavour oscillation parameters from the fit to global data after the TAUP 2013 conference from [3]. The reactor fluxes have been left free in the fit and short baseline reactor data (RSBL) with $L \lesssim 100 \text{ m}$ are included.*

This arises the question on whether the new Planck result could be used to infer some general properties of the neutrino mass matrix and, in particular, to discard some of the neutrino mass textures compatible with the oscillation data. To be predictive, one generally expect that some of the elements of the neutrino mass matrix must be vanishing or strongly related. Here we focus on the first class of matrices; among the Majorana mass matrices with two-zero entries, we restrict our analysis to the five models still compatible with the data and having a non-vanishing Majorana effective mass $|\langle m \rangle|$ for the neutrinoless double β -decay ($((\beta\beta)_{0\nu}$ -decay); according to [9, 10], from which we also adopt here the nomenclature, the interesting textures are:

⁴In this paper we will use the fit results summarized in Table 1 of [3]; the outcome of our analysis does not change if other data set are used.

$$\begin{aligned}
B_1 : \quad & \begin{pmatrix} a_1 & a_2 & 0 \\ a_2 & 0 & a_3 \\ 0 & a_3 & a_4 \end{pmatrix}, & B_2 : \quad & \begin{pmatrix} a_1 & 0 & a_2 \\ 0 & a_3 & a_4 \\ a_2 & a_4 & 0 \end{pmatrix}, & B_3 : \quad & \begin{pmatrix} a_1 & 0 & a_2 \\ 0 & 0 & a_3 \\ a_2 & a_3 & a_4 \end{pmatrix}, \\
& & & & & & & & & (2) \\
B_4 : \quad & \begin{pmatrix} a_1 & a_2 & 0 \\ a_2 & a_4 & a_3 \\ 0 & a_3 & 0 \end{pmatrix}, & C : \quad & \begin{pmatrix} a_1 & a_2 & a_3 \\ a_2 & 0 & a_4 \\ a_3 & a_4 & 0 \end{pmatrix}.
\end{aligned}$$

All these textures give rise to a QD neutrino mass spectra and can therefore be constrained or even ruled out by current and forthcoming experimental results coming from cosmology and from the next generation of $(\beta\beta)_{0\nu}$ -decay experiments.

In the present work we want to study the compatibility of these patterns with the present data using the best fit values of Table 1 and show which ones are already saturating the current bounds obtained by cosmological observations and other source of data such as $(\beta\beta)_{0\nu}$ -decay limits, taking into account the octant degeneracy of θ_{23} . It is worth noticing that a recent global fit analysis has been performed [11] in which possible hints related to the value of the Dirac phase δ responsible for CP violation in the lepton sector and to the octant of θ_{23} in NO emerge. This up-to-date analysis comes from the combination of different kind of data, e.g. reactor and accelerator experiments, and of their interplay with solar and atmospheric data and seems to indicate a preferred value for the Dirac phase $\delta \sim 3\pi/2$ —specifically $\delta = 1.39(1.35)\pi$ for NO (IO) and for the octant of θ_{23} in the first octant for NO (for IO two independent regions still exist at 1σ). In what follows we will comment more on these indications; however, our numerical analysis will be mainly based on the results of the global fit performed in [3] where no preferred octant for θ_{23} in NO emerged from their global analysis, since we want to study the dependence of the textures in eq. (2) on the two possibilities for θ_{23} . We will use the Planck result to show that, for normal ordering, the texture C is ruled out at a high confidence level and we will show that a future measurement of the octant of θ_{23} will put sever constraint on the possible structure of the Majorana mass matrix. We will show also the implication of the above mentioned correlations for $(\beta\beta)_{0\nu}$ -decay, for both normal and inverted orderings.

2 General Approach and Results

The mixing of three light massive neutrinos ν_i , $i = 1, 2, 3$, in the weak charged lepton current is described by the Pontecorvo, Maki, Nakagawa, Sakata (PMNS) 3×3 unitary mixing matrix, U_{PMNS} . In the standard parametrisation [12], U_{PMNS} is expressed in terms of the solar, atmospheric and reactor neutrino mixing angles θ_{12} , θ_{23} and θ_{13} , respectively, and one Dirac - δ , and two Majorana [13] - α_{21} and α_{31} , CP violating (CPV) phases:

$$U_{\text{PMNS}} \equiv U = V(\theta_{12}, \theta_{23}, \theta_{13}, \delta) Q(\alpha_{21}, \alpha_{31}), \quad (3)$$

where

$$V = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad (4)$$

and we have used the standard notation $c_{ij} \equiv \cos \theta_{ij}$, $s_{ij} \equiv \sin \theta_{ij}$ and

$$Q = \text{Diag}(1, e^{i\alpha_{21}/2}, e^{i\alpha_{31}/2}). \quad (5)$$

Therefore the Majorana mass matrix of neutrinos in the flavour basis can be written as:

$$M_\nu = M_\nu^T = U \text{diag}(m_1, m_2, m_3) U^T \quad (6)$$

Texture	(m_1, m_2, m_3) [eV]	$\pm(\delta, \alpha_{21}, \alpha_{31})$	$ \langle m \rangle $ [eV]	Σ [eV]
$B_1 (\theta_{23}^\ell)$	$(6.27, 6.33, 7.97) \times 10^{-2}$	$(91.7, 5.61, 183.8)^\circ$	6.32×10^{-2}	0.206
$B_2 (\theta_{23}^u)$	$(4.53, 4.61, 6.69) \times 10^{-2}$	$(86.96, 349.45, 172.77)^\circ$	4.59×10^{-2}	0.158
$B_3 (\theta_{23}^\ell)$	$(6.66, 6.71, 8.28) \times 10^{-2}$	$(91.96, 355.95, 177.15)^\circ$	6.71×10^{-2}	0.216
$B_4 (\theta_{23}^u)$	$(4.84, 4.92, 6.90) \times 10^{-2}$	$(92.66, 6.61, 184.65)^\circ$	4.90×10^{-2}	0.167

Table 2: Numerical solutions for several neutrino observables corresponding to the best fits in Table 1 for NO. We employ the values of θ_{23} given for both octants (ℓ lower and u upper octants).

Texture	(m_1, m_2, m_3) [eV]	$\pm(\delta, \alpha_{21}, \alpha_{31})$	$ \langle m \rangle $ [eV]	Σ [eV]
$B_1 (\theta_{23}^u)$	$(6.68, 6.73, 4.61) \times 10^{-2}$	$(90.01, 355.10, 176.43)^\circ$	6.64×10^{-2}	0.180
$B_2 (\theta_{23}^\ell)$	$(7.98, 8.03, 6.35) \times 10^{-2}$	$(90.08, 3.46, 182.50)^\circ$	7.95×10^{-2}	0.224
$B_3 (\theta_{23}^u)$	$(6.89, 6.95, 4.91) \times 10^{-2}$	$(90.56, 6.44, 184.44)^\circ$	6.85×10^{-2}	0.188
$B_4 (\theta_{23}^\ell)$	$(8.28, 8.32, 6.72) \times 10^{-2}$	$(89.71, 356.04, 177.28)^\circ$	8.24×10^{-2}	0.233
$C (\theta_{23}^\ell)$	$(8.35, 8.39, 6.81) \times 10^{-2}$	$(72.10, 281.40, 123.00)^\circ$	6.79×10^{-2}	0.235
$C (\theta_{23}^u)$	$(6.39, 6.45, 4.19) \times 10^{-2}$	$(118.89, 111.28, 265.44)^\circ$	4.15×10^{-2}	0.170

Table 3: Numerical solutions for several neutrino observables corresponding to the best fits in Table 1 for IO. We employ the values of θ_{23} given for both octants (ℓ lower and u upper octants).

where m_1, m_2, m_3 can be chosen real and positive. The data coming from oscillation experiments constrain the neutrino mass spectrum to be either i) normal ordered (NO): $m_1 < m_2 < m_3$, $\Delta m_{31}^2 > 0$, $\Delta m_{21}^2 > 0$, $m_{2(3)} = (m_1^2 + \Delta m_{21(31)}^2)^{1/2}$; or ii) inverted ordered (IO): $m_3 < m_1 < m_2$, $\Delta m_{32}^2 < 0$, $\Delta m_{21}^2 > 0$, $m_2 = (m_3^2 + \Delta m_{23}^2)^{1/2}$, $m_1 = (m_3^2 + \Delta m_{23}^2 - \Delta m_{21}^2)^{1/2}$. For a range of the lightest neutrino mass $\gtrsim 0.10$ eV the neutrino mass spectrum is said to be quasi-degenerate with $m_1 \cong m_2 \cong m_3$, $m_j^2 \gg |\Delta m_{31(32)}^2|$ with $j = 1, 2, 3$ while it is NO if $m_1 \ll m_2 < m_3$, $m_2 \cong (\Delta m_{21}^2)^{1/2}$, $m_3 \cong (\Delta m_{31}^2)^{1/2}$ or IO if $m_3 \ll m_1 < m_2$, with $m_{1,2} \cong |\Delta m_{32}^2|^{1/2}$.

The matrix M_ν is described altogether by nine parameters: the three masses, three mixing angles and three CPV phases. The textures in eq. (2) are particularly interesting since the two zero entries impose four independent constraints on the mixing parameters. Considering the experimental values on the three mixing angles θ_{ij} , and the two squared mass differences Δm_{21}^2 and $\Delta m_{31(32)}^2$ we have in total nine relations that allow to fix all the parameters of M_ν , including the CPV phases δ, α_{21} and α_{31} . Details on this procedure can be found, among others, in refs. [9, 10]. We have updated the predictions from the five textures on the values of the neutrino masses, CPV phases, the Majorana effective mass $|\langle m \rangle|$ in the $(\beta\beta)_{0\nu}$ -decay and the sum of the neutrino masses Σ , using the best fit values quoted in Table 1. Our results are given in Tables 2 and 3, where we list the numerical solutions for the above-mentioned neutrino observables for NO and IO spectrum, respectively.

First of all, from our numerical results it is clear that within the analyzed textures only QD spectrum is possible for the three light active neutrinos. This is particularly important in view of the recent cosmological results and the next generation of $(\beta\beta)_{0\nu}$ -decay experiments which can strongly constrain or even rule out the textures under study. For the textures of type B, the values of the Majorana phases are near CP conserving values (similarly to what found in [10]), whereas the Dirac CP phase δ for both orderings is approximately $\pm\pi/2$. Interestingly enough, these values seem to be compatible with the intriguing indication suggested in [11].

From Table 2 and 3 it is evident that the NO is possible only for the textures B_1 and B_3 (B_2 and B_4) when the value of θ_{23} in the lower (upper) octant is used while IO is possible if B_1 and B_3 (B_2 and B_4) are associated with the upper (lower) θ_{23} value. Finally, the texture C only allows for IO using both values of θ_{23} while the NO in the case of the current best fit values is not consistent

(in other words, as explained in [14], this texture predicts θ_{23} to be almost maximal). In addition, in this case the Dirac CPV phase is drifting apart from its maximal value.

Looking at Tables 2 and 3, we also have to notice that some of the B textures, namely $B_1(\theta_{23}^\ell)$ and $B_3(\theta_{23}^\ell)$ for NO and $B_2(\theta_{23}^u)$, $B_4(\theta_{23}^u)$ and $C(\theta_{23}^\ell)$ for IO, correspond to a value of Σ that, for the present best fit values, is near to the current cosmological bound given in eq. (1) and therefore they are now close to be strongly constrained. Moreover all these textures, independently of the octant of θ_{23} , have a range for $|\langle m \rangle| > 10^{-2}$ eV (as a consequence of the QD spectrum), which is the range planned to be exploited by the next generation of $(\beta\beta)_{0\nu}$ -experiments.

In Fig. 1 we show for the textures under study the values of $|\langle m \rangle|$ versus the lightest neutrino mass in the NO (Left Panel- B textures only) and IO (Right Panel- all textures) considering 3σ uncertainty in the oscillation parameters. Since the regions identified for the textures of type B are partially overlapping, we display B_1 and B_2 in the upper plots and B_3 and B_4 in the lower ones. It is clear from the plots that part of the solutions are strongly disfavoured (especially in the IO case) by the upper limit $m_{\min} \lesssim 0.07$ eV implied by eq.(1) (solid vertical line); the recent combined $(\beta\beta)_{0\nu}$ -decay limit $T_{0\nu}^{1/2}(^{76}\text{Ge}) > 3.0 \times 10^{25}\text{y}$ (90% CL) [15], corresponding to minimal values of $|\langle m \rangle|$ in the range $(0.2 - 0.4)$ eV, is less effective in this respect.⁵ From Fig. 1 one can also appreciate that even using a more conservative limit given by the Planck Collaboration on the sum of the neutrino masses, i.e. $\Sigma < 0.66$ eV, implying $m_{\min} \lesssim 0.22$ eV (dashed vertical line in the plots) part of the solutions found for the textures of type B and C in the case of NO and IO are now excluded.

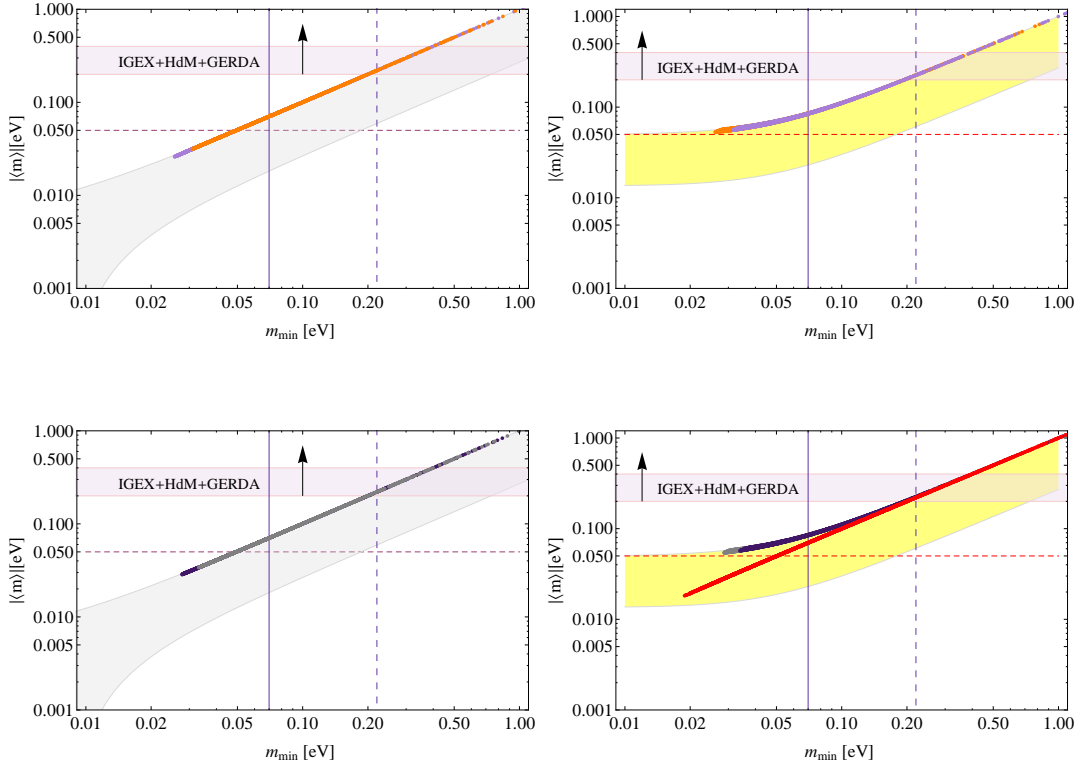


Figure 1: The plots show $|\langle m \rangle|$ as a function of the lightest neutrino mass for NO (Left Panel) and IO (Right Panel) using 3σ uncertainty in the oscillation data. The upper plots refer to B_1 and B_2 textures, the lower ones to B_3 and B_4 . We used different colors to distinguish the textures, given as follows: B_1 in orange, B_2 in violet, B_3 in gray, B_4 in black, C in red (only for IO). The solid vertical line is the Planck limit on $m_{\min} = 0.07$ eV, whereas the dashed one represents the value $m_{\min} = 0.22$ eV implied by the more conservative constraint $\Sigma < 0.66$ eV. The region above the horizontal lines (as indicated by the arrow) is now excluded, according to the analysis presented in [15]. The dashed horizontal line represent future sensitivity for the $(\beta\beta)_{0\nu}$ -decay process.

⁵The band of minimal values are obtained considering as standard mechanism the exchange of a light Majorana neutrino and different sets of nuclear matrix elements.

In the light of the Planck results, we find particularly interesting to study with some details the correlations implied by the textures B_{1-4} and C between the neutrino masses (and their sum) and the atmospheric angle, the worst known mixing angle up to now. In order to do that, it is necessary to express the neutrino masses in terms of θ_{23} ; referring to the approximate results reported in [10] (still good with the mixing parameter values of Tab.1), we have:

- Textures B_1 and B_3 (for NO or IO):

$$m_1 \approx m_2 \approx m_3 \tan^2 \theta_{23}, \quad m_3 \approx \sqrt{\frac{\Delta m_A^2}{1 - \tan^4 \theta_{23}}}, \quad (7)$$

- Textures B_2 and B_4 (for NO or IO):

$$m_1 \approx m_2 \approx m_3 \cot^2 \theta_{23}, \quad m_3 \approx \sqrt{\frac{\Delta m_A^2}{1 - \cot^4 \theta_{23}}}, \quad (8)$$

where $\Delta m_A^2 = \Delta m_{31(32)}^2$ for NO (IO). Texture C is a bit more complicated since the parameter space for NO is reduced to values of θ_{23} very close to maximal mixing whereas the one for IO is much larger. In the latter case, taking full advantage of the analytical results presented in [10], we get:

$$\begin{aligned} m_3 &\sim \sqrt{\Delta m_A^2} s_{13} \cot \theta_{12} |\tan 2\theta_{23}| (1 - s_{13} \cot \theta_{12} \tan 2\theta_{23}), \\ m_2 &\sim \sqrt{\Delta m_A^2} |\tan 2\theta_{23}| \left(\frac{s_{13}^2 \cot^2 \theta_{12} + 2 \cot^2 2\theta_{23}}{2 |\cot 2\theta_{23}|} \right), \\ m_1 &\sim \frac{\sqrt{\Delta m_A^2} |\tan 2\theta_{23}|}{2 |\cot 2\theta_{23}|} \left[2 \cot^2 \theta_{12} \cot^2 2\theta_{23} - 2 s_{13} \cos \delta \cot \theta_{12} \cot 2\theta_{23} \csc^2 \theta_{12} + \right. \\ &\quad \left. s_{13}^2 (1 + \cos^2 \delta (1 + 2 \cos 2\theta_{12}) \csc^4 \theta_{12}) \right]. \end{aligned} \quad (9)$$

All the previous expressions are obtained for small θ_{13} ; however, we checked that they are valid within 10% with respect of the exact values obtained using the best fit values of Table 1.

In the NO, on the other hand, the ratios among the complex neutrino masses λ_i computed for $\theta_{23} = \pi/4$ are given by:

$$\frac{\lambda_1}{\lambda_3} = \frac{\lambda_2}{\lambda_3} = -\frac{c_{13}^2}{1 + s_{13}^2 e^{2i\delta}}, \quad (10)$$

which gives degenerate m_1 and m_2 . In order to reproduce the solar squared mass difference, the atmospheric angle must depart from its maximal value by very small quantities, otherwise the ratio $r \equiv \Delta m_{21}^2 / \Delta m_{31}^2$ would be too large. This points towards a very small dependence of the neutrino masses on θ_{13} , so as for Σ .

We are now in the position to express $\sin^2 \theta_{23}$ as a function of Σ ; approximate expressions are the following:

- Textures B_1 and B_3

$$\sin^2 \theta_{23} = \left(-\Sigma^2 - \Delta m_A^2 + \Sigma \sqrt{\Sigma^2 + 3\Delta m_A^2} \right) / \Delta m_A^2 \quad (11)$$

- Textures B_2 and B_4

$$\sin^2 \theta_{23} = \left(\Sigma^2 + 2\Delta m_A^2 + \Sigma \sqrt{\Sigma^2 + 3\Delta m_A^2} \right) / \Delta m_A^2. \quad (12)$$

In Fig. 2 we show the numerical correlation between $\sin^2 \theta_{23}$ and Σ for the textures of type B analyzed in this paper. The horizontal light and the strong shaded band correspond respectively to the 3σ and 1σ uncertainties in the mixing angles and two squared mass differences while the solid vertical lines correspond to the Planck limit of eq. (1). The solid black lines represent the approximate expressions given above for the $\theta_{23} - \Sigma$ correlations, eqs. (11) and (12).

As already indicated by the analysis of the textures at the best fit values, one can see in the left (right) panel that the textures B_1 and B_3 (B_2 and B_4) are compatible only with the value of θ_{23} in the lower (upper) octant. Given the 3σ ranges on θ_{23} , the Planck limit already rules out part of the correlations implied by the four textures, for both NO and IO. A closer look at the 1σ level, however, shows more interesting results; in fact, for the NO case (left panel), the Planck limit does rule out part of the correlation predicted by the textures $B_{1,3}$ (thus, only if θ_{23} will result to be smaller than maximal mixing, as obtained in [11]). A similar situation also happens in the IO case (right panel) for the textures $B_{2,4}$. We stress again that at the 3σ level no definite conclusions can be drawn.

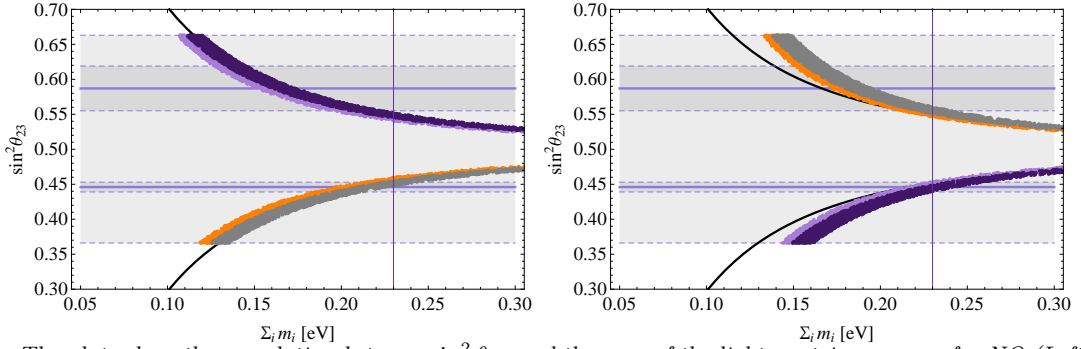


Figure 2: The plots show the correlation between $\sin^2 \theta_{23}$ and the sum of the light neutrino masses for NO (Left Panel) and IO (Right Panel). The Textures are given as follows: B_1 in orange, B_2 in violet, B_3 in gray, B_4 in black, C in red (only for IO). The area on the right of the solid vertical line represents the constrain of eq. (1) given by Planck [4] and is therefore strongly disfavoured while the two strong shaded horizontal bands corresponds to 1σ uncertainty in the octant degeneracy in the determination of θ_{23} . Solid black lines represent the approximate expressions of eqs. (11) and (12).

For texture C , in the NO case and for maximal θ_{23} we get a simple expressions for Σ :

$$\Sigma = \sqrt{\Delta m_A} \frac{[3 - s_{13}^2(2 - \cos 2\delta)]}{2s_{13}|\cos \delta|}. \quad (13)$$

This expression has a minimum value corresponding to CP conserving values of $\delta = (0, \pi)$; for the intervals of the mixing parameters reported in Tab.1, this gives:

$$\Sigma_{min} \sim 0.45 \text{ eV}. \quad (14)$$

This is the main result of the paper, in that the Planck result on the sum of the neutrino masses completely excludes the texture C as a viable Majorana mass matrix to describe the neutrino properties. For the IO case the expression of the masses in eq. (9) shows a complicate dependence on θ_{23} , so we prefer to give Σ as a function of θ_{23} and not viceversa; we get:

$$\Sigma = \frac{\sqrt{\Delta m_{21}^2}}{2} [2 \csc^2 \theta_{12} - 2s_{13} \cot \theta_{12} \tan 2\theta_{23}(-1 + \cos \delta \csc^2 \theta_{12}) + s_{13}^2(-2 \cos \delta \cot^2 \theta_{12} + \csc^2 \theta_{12} + \cos^2 \delta(1 + 2 \cos 2\theta_{12}) \csc^4 \theta_{12} \tan^2 2\theta_{23})].$$

In Fig. 3 we show in the left panel the correlation between the $\sin^2 \theta_{23}$ and Σ for the texture C in the case of IO. We notice that the values of θ_{23} selected in our numerical analysis for IO do not prefer any specific octant and the same considerations of the type B textures apply. However, if one considers the 1σ uncertainty in the octant degeneracy, the numerical solutions we found for the lower value of θ_{23} are constrained in a narrow interval corresponding to values for the Σ very near

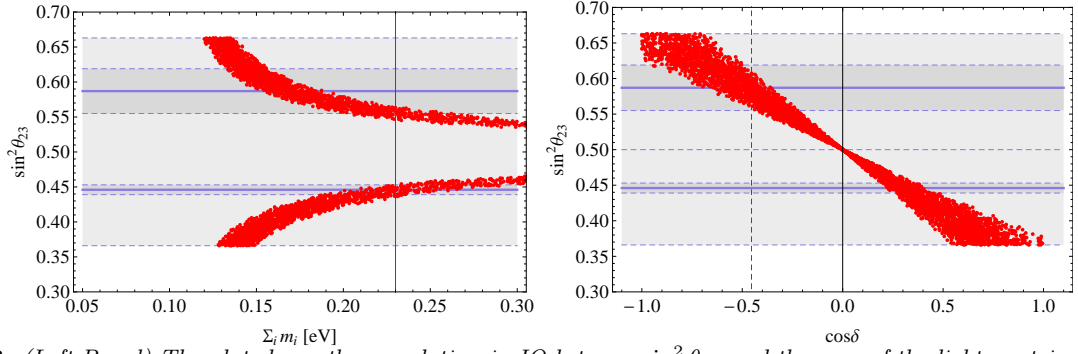


Figure 3: (Left Panel) The plot shows the correlation in IO between $\sin^2 \theta_{23}$ and the sum of the light neutrino masses for the texture C . The area on the right of the solid vertical line is strongly disfavoured by the Planck data. As in Fig. 2, the strong shaded area corresponds to the 1σ uncertainty in the determination of θ_{23} . (Right Panel) We show the corresponding correlation between $\sin^2 \theta_{23}$ and $\cos \delta$. The dashed vertical line corresponds to the preferred best fit values for δ given in the global fit analysis of Ref. [11].

to the Planck limit while a 1σ uncertainty in the upper value of θ_{23} is compatible with a broader area. It is interesting to observe that the correlation between the value of δ and $\sin^2 \theta_{23}$ is such that the best fit for δ of [11] (dashed vertical line in the right panel of Fig. 3) points towards a second octant solution for θ_{23} , already at the 1σ level.

In conclusion, we have reanalyzed some of the two-zero neutrino textures in the light of the recent Planck result on the masses of the light neutrinos and we have shown that texture C is not compatible with the normal ordering of the neutrino mass eigenstates. As a byproduct, we have also shown that, taking the atmospheric angle with a 1σ uncertainty and in the first octant, strong constraints are put on the matrices of B types, which allow to disfavor $B_{1,3}$ in NO and $B_{2,4}$ in IO.

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